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Statistical Power Comparison of Two Sampling Protocols for Riverine Snails

Abstract

We compared the statistical power of two alternative sampling designs to detect changes in threatened and endangered snail species populations in the Mid-Snake River (Idaho). Our goal was to determine which sampling approach would have the best chance of detecting a change associated with different hydroelectric project management scenarios. We summarized the data as 1) the average number of snails collected across quadrats (density/m^2) and 2) the proportion of quadrats that had snails present. We calculated the minimum detectable difference that each measure could detect with a two-sample *t* test. The density measure was highly variable and even a complete loss of snails failed to represent a statistically significant change for most sites. The precision improved somewhat when density was log-transformed, the number of replicate quadrats was increased, and larger sampling quadrat used; however, statistical power to detect change remained low.

In contrast, proportion measures were much more precise and could detect a 34% reduction in the proportion of quadrats with snails present. When the number of quadrats was increased to 30, a 24% change could be detected and for 50 quadrats an 18% change. Proportion of quadrats with snails present was also highly correlated with the average density of snails (Pearson's r = 0.91). In addition to being a more sensitive indicator, the proportion measure is quicker to observe for each sample which means that a larger area can be surveyed during the same amount of time.

Introduction

Monitoring plans designed to assess biological populations typically involve long term data collection under uncertain conditions. Statistical power analysis provides a framework to evaluate whether the data collected can protect the resource by detecting a reasonable level of change (Ward et al. 1986, Peterman 1990, Thomas 1996). Statistical power is defined as the probability of detecting a change given that a change has truly occurred. The ability of a monitoring design to detect change depends on the variance of the sample estimates, the number of samples, the magnitude of the change (effect size), and the level of uncertainty accepted for the test (α). Although key to the success of any monitoring program, statistical power analysis is rarely considered when agencies develop long-term sampling plans (Ward et al. 1986, Dayton 1998, Gibbs et al. 1999).

In this study, we used statistical power analysis to evaluate the relative merits of two population measures for detecting change through time: 1) density, measured as the number of snails per unit area, and 2) proportional occurrence, measured as the proportion of quadrats with snails present. Federal re-licensing of five hydroelectric dams in the Mid-Snake River (Idaho, USA) triggered population assessments for two hydrobiid snails listed as threatened or endangered under the Endangered Species Act (ESA; Smith et al. 2001, Norris 2004). The Bliss Rapids snail (BRS), *Taylorconcha serpenticola*, has been listed as threatened and the Idaho springsnail, *Pyrgulopsis idahoensis*, listed as endangered (Pilsbry 1933, Turgeon et al. 1988, U.S. Fish and Wildlife Service 1992, Hershler et al. 1994, Frest and Johannes 2000). Hershler and Liu (2004) recently synonomized *P. idahoensis* with *P. robusta*, the Jackson Lake springsnail (JLSS); therefore, we follow their nomenclature in this paper. The purpose of this analysis was to develop a monitoring plan with sufficient statistical power to detect changes in snail populations should they occur as a result of dam operation.

Methods

Study Area

The Snake River is the largest tributary of the Columbia River and flows from its headwaters

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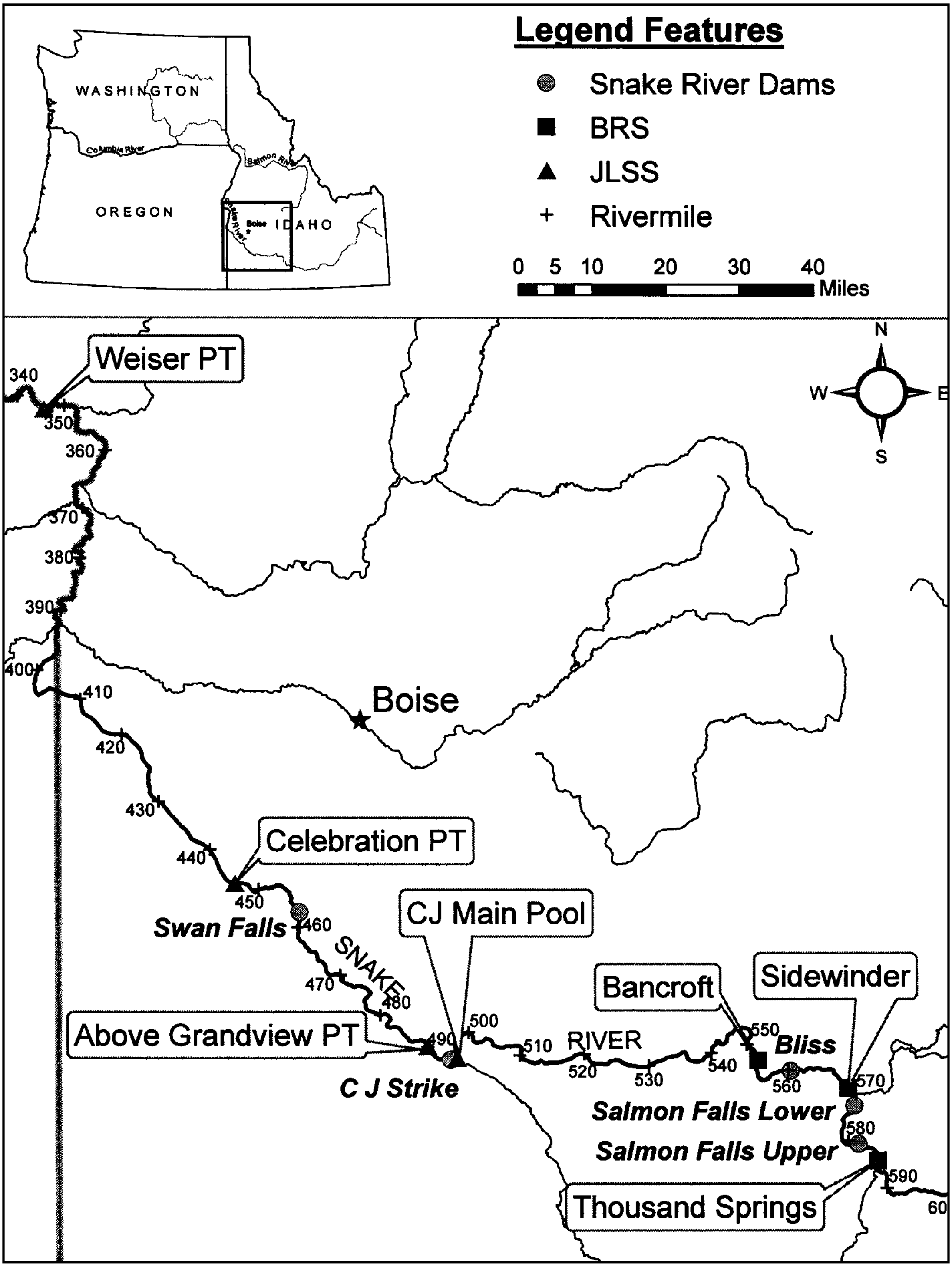

Figure 1. Hydroelectric projects and snail sampling locations on the Snake River.

in northwestern Wyoming for over 1,670 km through Idaho, Oregon, and Washington. In south central Idaho, the Mid-Snake cuts through basalt geology and flows through agricultural areas and native sagebrush-steppe vegetation. The Mid-Snake represents much of the known habitat for the two listed species of Gastropoda (Figure 1). Both species are somewhat rare in the Snake River and are typically found in discrete, isolated colonies but may be more widely distributed in some locations.

Colonies of JLSS were found in the lower reach of the Mid-Snake where the gradient is lower and the substrate composed of finer material; colonies of BRS were found in the upper reaches. Hershler and Liu (2004) report finding JLSS near springs or spring-fed streams. In contrast, three of our four sampling locations in the Mid-Snake were not known to be near springs. In fact, the colony at C. J. Strike main pool was located along the banks of a reservoir cove with very low water velocity. JLSS colonies were found in substrates composed of silt to pebble, but with cobble and boulder present. Colony size ranged from 15–75 m^2.

BRS were collected from two sites along the Mid-Snake River and one site adjacent to the Snake at Thousand Springs. Colonies of BRS were located on rocky substrate adjacent to or downstream from springs and in main stem river areas with spring influence, which agreed with observations made by Hershler et al. (1994). Colony size ranged from 20–300 m^2.

Snail Collection

Snails were collected using a Venturi suction-dredge to sample a 0.25 m^2 (1 m x 0.25 m) quadrat placed on the substrate. Quadrat placement depended on the size of the colony. At each location, the width of the colony was measured along the shoreline and four transects placed at regular intervals perpendicular to the shore. The location of the first transect was assigned randomly. The first quadrat on each transect was located at the water's edge. Placement of additional quadrats on each transect also depended on the size of the colony; each quadrat was placed at regular intervals along the transect to sample the entire colony. At each sample site, 16 quadrats were sampled.

Live snails were sorted from debris using sieves, identified in the field (with voucher specimens preserved for taxonomic verification), and returned to their area of collection. Detailed description of sampling sites and methods are presented in Stephenson et al. (2004).

Quadrats were located 0–2 m below the water surface. Depth varied by location and depended on the terrain at a particular site. Although snails were not typically found below 2 m, density was not strongly associated with depth in the areas in which snails were found (Fore and Clark, unpublished data); therefore, we did not consider depth in our analysis.

Statistical Power Analysis

At each of the seven sampling sites, we measured snail populations in two ways: 1) snail density, measured as the average number of snails per quadrat, and 2) the proportion of quadrats with snails present. For both measures we calculated the minimum detectable difference (MDD) that we could potentially detect for a two-sample *t* test (Cohen 1988, Zar 1999). The MDD represents the smallest difference between the mean of two groups that would indicate a statistically significant change in snail density or proportion. For snail density, we calculated MDD as follows:

$$\mathrm{MDD} \geq \sqrt{\frac{2s^2}{n}}\left(t_{\alpha(1),\nu} + t_{\beta(1),\nu}\right),$$

Where s^2 = the variance of snail density derived from replicate quadrats at each site,

n = the number of quadrats,

$t_{\alpha(1),\nu}$ = the *t* value for alpha of 0.10 for a 1-sided test,

$t_{\beta(1),\nu}$ = the *t* value for beta of 0.10 for a 1-sided test, and

$\nu = 2n - 2$.

For this analysis, we selected values for α and β *a priori* and used variance estimates derived from the data to solve for the MDD. We selected a 1-sided test because we were only interested in testing for a decline in snail populations due to dam operations. No change or an increase in snails represented similar outcomes.

We used data from each sampling location to estimate the variance of snail density, and then calculated the MDD separately for each sampling location. We repeated the analysis using log-transformed data because snail density may be a function of an underlying multiplicative process associated with exponential growth (Limpert et al. 2001).

For the proportion of quadrats with snails present we performed a similar analysis to determine the MDD; however, the calculation of variance was slightly different because only a single value for proportion (ranging from 0 to 1) could be derived for each site (Cohen 1988). The underlying statistical distribution for this proportion is the binomial because for each quadrat the target species may be either present or absent. The variance associated with an estimate of proportion depends on the proportion itself in that proportions closer to 0.5 have higher variance than proportions closer to 0 or 1. As a consequence, proportions must be transformed to stabilize their variance. We used the following equation to transform our observed proportions:

$$p' = 2 \arcsin \sqrt{p}.$$

The variance for the proportion transformed in this way is equal to 1/n. Thus, the equation for the MDD becomes

$$\text{MDD} \geq \sqrt{\frac{2}{n}} \left(t_{\alpha(1),\nu} + t_{\beta(1),\nu} \right)$$

Where n = the number of quadrats, and

$t_{\alpha(1),\,\nu}$, $t_{\beta(1),\,\nu}$, and ν were defined as above for density.

Influence of Sample Size on Statistical Power

Using the formulae above, we calculated MDD for different numbers of quadrats by substituting different values for n and using estimates of variance derived from our field data. For this study, 16 quadrats at each location provided a reasonable estimate of the variance associated with density and we do not expect the variance estimate to change with additional quadrats. In contrast, the variance of both the *mean* of density and the *proportion* of quadrats with snails present do decline as more quadrats are sampled because the variance of the mean declines as n increases. This relationship is reflected in the equations above for which n is represented in the denominator. Data from additional quadrats is not needed to evaluate the influence of sample size on n, rather the equations above can be used with new values for n.

Influence of Variance on MDD

To generalize our results to other animal populations, we modified our variance estimates for JLSS density measures by multiplying the observed standard deviation by 0.5, 0.25, and 0.1. We also calculated the corresponding coefficient of variation (CV) because it is most frequently reported in the literature to compare the variability of abundance measures across studies (Gibbs et al. 1998).

$$CV = \frac{s.d.}{\bar{X}} * 100\%$$

Where s.d. = the standard deviation of density (number of snails per quadrat), and

$\bar{X}$ = density averaged across quadrats.

Modification of the standard deviation yielded equivalent changes to the CV values that were one-half, one-quarter and one-tenth the magnitude of ours. We then calculated the MDD for these simulated estimates of variance.

Influence of Quadrat Size on MDD

We tested whether larger quadrat sizes would reduce the variance of density measures and increase the precision of estimates. We did not collect larger samples in the field; instead we combined the data from 0.25 m^2 quadrats in the computer to obtain quadrat sizes of 1, 1.5, and 2 m^2. We kept the level of field effort constant for the new quadrat sizes when we computed variance and MDD as described above. As an example, the original sampling design had sixteen 0.25 m^2 quadrats; therefore, for the 1 m^2 quadrats which were four times larger, we used only four replicates to keep the field effort equal. We used data from all seven sites for this comparison.

Results

Snail Density (Number of Snails/0.25 m^2)

The MDD for snail density that we could potentially detect was greater than the mean for all sites but one (CJ Main Pool) which meant that a complete loss of snails (mean density = 0) would be too small a change to be statistically significant for the number of quadrats used (Table 1).

Log Transformation of Snail Density (ln[Number of Snails/0.25m^2])

After applying a logarithmic transformation to the counts of snails/0.25 m^2, variance estimates

TABLE 1. Site name, river mile, target species, mean number of snails found per 0.25 m^2 (snail density), standard deviation of snail density, minimum detectable difference (MDD; 1-sided test, $\alpha = 0.1$, $n = 16$), mean snail density minus the MDD, and mean snail density minus the MDD for log-transformed data (antilog values are shown).

Location	River Mile	Species	Mean	SD	MDD	Mean – MDD	Mean – MDD (log transform)
Weiser	345.8	JLSS	10.3	17.3	16.1	-5.7	-0.15
Celebration	446.2	JLSS	59.8	96.3	89.2	-29.3	2.24
Above Grandview	489.5	JLSS	309	366.6	339.7	-30.7	73.5
CJ Strike	495.1	JLSS	30.2	19.7	18.3	11.9	11.38
Bancroft	552.8	BRS	2.4	4.0	3.7	-1.3	-0.04
Sidewinder	570.2	BRS	2.2	3.0	2.8	-0.6	-0.11
Thousand Springs	585	BRS	257.9	406.4	376.5	-118.7	7.52

TABLE 2. Site name, river mile, target species, proportion of quadrats with snails observed, and the proportion that would need to be observed to represent a statistically significant decrease for 16, 30 and 50 quadrat samples.

Location	River Mile	Species	Proportion	Significant change		
				N = 16	N =30	N = 50
Weiser	345.8	JLSS	0.50	0.11	0.19	0.25
Celebration	446.2	JLSS	0.87	0.46	0.58	0.66
Grandview	489.5	JLSS	1.00	0.81	0.89	0.94
CJ Strike	495.1	JLSS	1.00	0.81	0.89	0.94
Bancroft	552.8	BRS	0.56	0.15	0.24	0.31
Sidewinder	570.2	BRS	0.44	0.07	0.15	0.20
Thousand Springs	585	BRS	0.88	0.48	0.60	0.67

associated with snail density were reduced. Lower variance translated into smaller values for the MDD, that is, a smaller detectable change. Nonetheless, the results were only slightly improved in terms of the ability of density to detect a change. Of the seven sites sampled, the MDD was still greater than the observed mean for three sites, and very close to the mean for two sites. Thus, for five out of seven sites, snail density was too variable to reliably detect a change (see Table 1). On average for the four JLSS sites, an 84% decline in snail density would represent a significant change. CV values for JLSS ranged from 24–121%; average CV was 57%. For the BRS sites, a 100% decline in snail density would represent a significant change.

Proportions (Number of Quadrats with Snails Present)

The proportion of quadrats with snails present ranged from 0.44 to 1.0 (Table 2). Based on 16 sample quadrats at a site, the minimum detectable change representing a significant decline in the proportion of quadrats with snails present ranged from 19–41% depending on location and averaged 34% across all seven sites.

Influence of Sample Size on Statistical Power

Increasing the number of quadrats sampled had a greater influence on the precision of the proportional measure than on the density measure (Figure 2). For log-transformed counts/0.25 m^2 (density) of JLSS, the minimum detectable change (averaged across all four JLSS sites) declined from 84.0% for 16 quadrats to 78.3% for 30 quadrats and declined further to 73.9% for 50 quadrats. In contrast, for the proportional measure the minimum detectable change started at a smaller value and declined more dramatically, from 33.7% (16 quadrats) to 24.4% (30 quadrats) and 18.3% (50 quadrats).

Influence of Variance on MDD

As expected, lower variance resulted in a smaller detectable difference for density estimates. Nonetheless, the percentage change that snail density could detect failed to approach the percentage change that proportion of quadrats with snails could detect, even after reducing the standard deviation (and the CV) to one-tenth of the values observed for our data (see Figure 2).

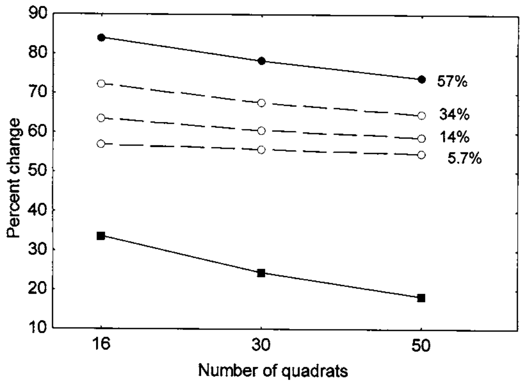

Figure 2. Percent change that snail population measures could detect for different sample sizes (16, 30 and 50 quadrats). Uppermost solid line is derived from measures of density for the JLSS data (snails/m^2). Dashed lines below represent power estimates derived from variance estimates that represent 10%, 25%, and 50% of the variance observed for the JLSS data. The coefficient of variance (CV) is shown to the right of each line. The lowest solid line represents the percent change that the proportional measure could detect. Lower values indicate greater sensitivity and greater power to detect change.

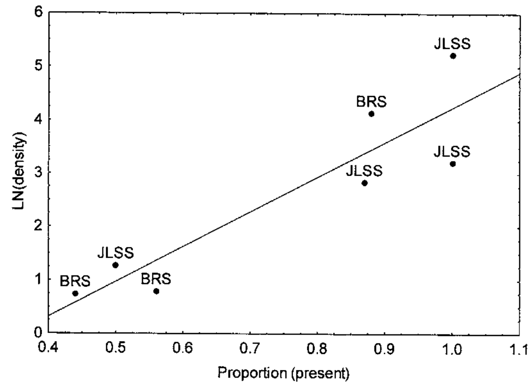

Figure 3. Proportion of quadrats with snails present was highly correlated with density (shown as the log transform of the average number of snails per 0.25 m^2; Pearson's r = 0.91). Shown are data for seven sampling locations for two different snail taxa.

Influence of Quadrat Size on MDD

Larger quadrat sizes translated into lower variance and greater precision when quadrats were combined in the computer. Averaged across all seven locations, the average percent decline that could be detected for 16 0.25 m^2 quadrats was 91%. Maintaining the same level of field effort, four 1 m^2 quadrats could detect a decline of 84%. Precision continued to increase with larger quadrat sizes: two 1.5 m^2 quadrats and two 2 m^2 quadrats could both detect a 63% decline in density.

Agreement Between Density and Proportion Measures

Although density and proportion measured different aspects of the snail populations, the agreement across all seven sites was very high between the two measures (Pearson's r = 0.91; Figure 3).

Discussion

Managing Snail Populations Under the ESA

Our purpose for this analysis was to determine the best method to assess the effects of hydroelectric dam operations on snail populations. During 2004–2009, snails will be sampled under two different dam operation scenarios: minimal flow alteration ("run of the river") and flow modifications associated with power generation ("load following"). We found that traditional approaches based on density estimates were inherently too variable to reliably detect any potential effects associated with dam operations. The high variability associated with density (counts/unit area) was reduced somewhat by taking larger sample quadrats, but, on average, a 63% or greater decline was still needed to conclude a significant change in density. In contrast, snail assessment based on proportional occurrence (presence/absence) provided a more precise measure and could detect a 34% reduction.

Although a stated purpose of the ESA is to "provide a means whereby the *ecosystems* upon which endangered species and threatened species depend may be conserved" (our italics), in practice, much of the monitoring associated with species protection and management boils down to counting the number of individuals of a listed species (Gibbs et al. 1998, Buckland et al. 2000). This project is no different with its narrow focus on listed snail species and dam operations. Both species in this study belong to a unique taxonomic group, the hyrobiid snails of the Western U.S., that is threatened in some areas by impoundments, habitat loss, and invasive exotics such as the New Zealand mud snail (*Potamopyrgus antipodarum*; Lydeard et al. 2004). Snails in this group may also be rare because they are relict species that evolved during very different geologic and climatic conditions. Thus, the methods and comparisons described here address the narrowly defined assessment process for listed snails, but may miss the bigger target of actual resource protection.

Defining an Acceptable Level of Uncertainty

Statistical power is defined as the probability of detecting a change should a change occur. When change is synonymous with degradation or loss of resources, the focus of a management agency becomes, in a practical sense, preservation of the status quo rather than the detection of a significant change. In this situation, failure to detect a change (Type II error) may be of greater concern or cost than a false alarm (Type I error). Dayton (1998) and Peterman (1990) describe the catastrophic losses of fisheries' stocks resulting from monitoring programs that protected against Type I errors by setting $\alpha = 0.05$ while ignoring the risk of Type II errors. Simple reporting of "no significant change" is insufficient for resource protection; the protocol must also have a demonstrated ability to detect a change should it occur (Peterman and M'Gonigle 1992, Taylor and Gerrodette 1993, Dayton 1998).

For these reasons, we set α and β equal in our analysis because we considered the probability of failing to detect a change (β) to be at least as important as the probability of falsely detecting a change (α; DiStefano 2003). Traditional hypothesis testing typically sets α equal to 0.05 and ignores β. Rather than restrict both to such small values, many authors recommend values of 0.1 when designing monitoring protocols using power analysis (Peterman 1990, Peterman and M'Gonigle 1992, Taylor and Gerrodette 1993, Steidl et al. 1997, Dayton 1998, Hoenig and Heisey 2001, DiStefano 2003).

Detecting Change

Although somewhat counterintuitive, this study demonstrated that more "coarse" data, i.e., presence/absence, may provide better information. Although we often expect that we can "fix" the high variability associated with population size estimates by taking more or larger samples, results from this study and similar studies undermine this common assumption. Increasing the number of quadrats for density measures even to very large values (>50) could not approach the level of precision observed for the proportion measure based on as few as 16 quadrats. Our results suggest that the simpler way may actually be the better way.

Low statistical power in population monitoring protocols is primarily due to high variability associated with measures of population size or density. Although our log-transformed estimates of snail density were quite variable (average CV = 57%), they were not unusual (Downing and Downing 1992). Gibbs et al. (1998) summarized data from 512 studies of 24 taxonomic groups and found CV values ranging from 14–131%. Thus, our observed CV values were below the median value for other published studies. Based on their analysis, Gibbs et al. (1998) recommend longer time periods for monitoring in order to compensate for high variability and low statistical power. For snail monitoring in the Mid-Snake, long term studies are not an option because information is needed within six years to inform decisions regarding how the hydropower projects can be operated while still protecting snails.

When we reframed the question to define a different response variable, i.e., proportion of quadrats with snails present, we were much more likely to detect changes should changes occur. From a biological point of view, the two approaches are not equivalent because density and proportional occurrence summarize different aspects of snail distributions. Snail density measures the number of snails per area; proportional occurrence measures the probability of snails being present within a given area. Nonetheless, both measures were highly correlated for this study, although this may not be the case for other organisms.

The appropriate choice of measure depends on what type of organism is being sampled, the inherent variability associated with counting numbers of organisms, and the pattern of their distribution across the sampling area. The primary advantage associated with counts/area is that it can provide estimates of total population size, which may be required in some situations, such as federal ESA listings (Smith et al. 2001). In contrast, an important advantage associated with presence/absence sampling is that a larger area can be sampled in the same amount of time. For a small snail in a large river, this may represent a significant advantage.

Acknowledgments

The authors thank R. Myers, M. Stephenson, B. Bean, and A. Foster for assistance with fieldwork, project support, and background information. M. Radko created the map figure. We thank B. Bean, L. Conquest, and an anonymous reviewer for their comments on the manuscript. The fieldwork was conducted under U.S. Fish and Wildlife Service Section 10 Permit #TE799558-4 and Idaho Department of Fish and Game Scientific Collecting Permits #F-11-93, #F-51-91, and #F-18-87.

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Received 10 October 2004
Accepted for publication 29 August 2005